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Editorial

Morphology Control in Organic Solar Cells

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Organic solar cells (OSCs) are a kind of device that can convert light energy into electrical energy, they possess the advantages of being lightweight, flexible, processable printing, and large-area production, and they are an effective way to alleviate energy deficiency and environmental pollution. Thanks to the rapid development of donor and acceptor materials, the optimization of active layer morphology, and the maturity of processing technology, the power conversion efficiency (PCE) of OSCs has exceeded 19%. Usually, OSCs consist of an anode, cathode, electron, a hole transport layer, and an active layer, and the device performance is closely related to the morphology of the active layer. As is well known, the photophysical conversion process of OSCs includes photon absorption, exciton diffusion, exciton separation, charge transport, and collection. In general, the thickness and constituents of the active layer have a profound influence on photon absorption. The efficiency of exciton diffusion is decided by the domain size of the active layer, the crystallinity and molecular orientation usually affect the process of exciton separation, and the interpenetrating network (bi-continuous phase separation) is conductive for charge transport and collection. However, the morphology of the active layer is uncontrollable due to the competitive coupling relationship between crystallization and phase separation. Hence, intensive efforts have been made to optimize the morphology of OSCs. In this editorial entitled "The Morphology Control in Organic Solar Cells", we will provide a comprehensive view of how to optimize the morphology of the active layer in order to expand the understanding of the relationship between morphology and device performance.

This editorial entitled "The Morphology Control in Organic Solar Cells" presents six papers, including improving the photon absorption efficiency by regulating the thickness of the active layer [1] and adding a third component to fabricate ternary solar cells [2], constructing an interpenetrating network through the combination of bilayers and post-annealing [3], enhancing the rigidity of molecules to improve the crystallinity [4], employing side-chain engineering to regulate the molecular orientation [5], and finally, a proposal for fabricating large-area and flexible OSCs with high device performance [6].

A brief summary of the content associated with each of the selected papers in this editorial is included below:

Photon absorption is crucial for exciton generation. The thickness of the active film plays an important role in the efficiency of photon absorption. In Muhammad Tahir [1], the authors studied the relationship between the optical properties, morphology, and thickness of the active layer. On the basis of the UV-vis absorption spectrum and AFM images, it is clear that some roughness and non-uniform surfaces are more suitable for better light capturing when the film thickness is within the appropriate range, i.e., 180 nm for PFB:PCBM blend, thus obtaining a higher short-circuit current density (J_{SC}). This work suggests that optimizing the thickness of the active layer is necessary to design a device with higher photovoltaic performance. The ternary strategy is also commonly recognized as a convenient and efficient means to improve the photon absorption of

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OSCs. In Emmanuel Kymakis [2], the authors introduce a ladder-type multi-fused ring 4,7-dithienbenzothiadiazole:thiophene derivative (named as compound T) into a PTB7:$PC_{71}BM$ blend. Due to the fact that the absorption range of compound T is from 350 to 550 nm, it complements the absorption of PTB7 and $PC_{71}BM$ very well. Thus, the ternary blend exhibits a broader absorption, which is a significant precondition for light harvesting. The addition of compound T resulted in a PCE of 8.34%, with an enhancement of 12% compared to the binary device. This work provides an effective strategy to overcome the deficiency of narrow absorption for organic semiconductors.

The ideal morphology of the active layer in OSCs is bulk heterojunction (BHJ), in which an interpenetrating network of large interfaces between continuous donor and acceptor domains is formed. The fabrication of BHJ is primarily based on phase separation during solution deposition, usually resulting in an uncontrollable phase-separated structure. In Jakub Rysz [3], the authors presented an intermixing method for the fabrication of BHJ through the combination of acceptor/donor bilayers and solvent vapor annealing. The results revealed that the interpenetration of donors and acceptors induced by solvent vapor annealing was dependent on solvent vapor and component compatibility. Moreover, the intermixing process was much slower, providing an opportunity to finely tune the morphology of the active layer. This general methodology provides a new method for fabricating high-performance OSCs, and its advantages may play a positive role in the commercialization of OSCs as well.

Conjugated molecules are semi-crystallized materials, and both the crystalline regions and amorphous regions exist in the films. Due to the lower barrier of charge transport in the crystalline region, the carrier mobility is higher than the one in the amorphous region. Hence, increasing the crystallinity of the active layer is an important way to improve charge transport and collection. In Dmitry Yu. Paraschuk [4], the authors investigated the effect of a branching core in star-shaped donor–acceptor molecules on physicochemical properties and charge transport. The results show that the molecules have a more rigid and planar core and are able to crystallize when compared to the twisty one, which results in higher hole mobility, thus an increased J_{SC} and improved PCE.

The structures of molecules are anisotropic in non-fullerene-based-OSCs. According to the arrangement of the backbone relative to the substrate, the molecular orientations are divided into edge-on, face-on, and flat-on orientations, which has great influence on carrier mobility. In Shirong Lu [5], the authors proposed a simple terminal alkyl chain engineering to fine-tune the molecular orientation toward high-performance all-small-molecule OSCs. Owing to the modified thermodynamic properties, the molecules, i.e., BT-RO-Cl and BT-REH-Cl, adopt a favorable combination of face-on and edge-on orientation, which formed a fluent 3D transport channel and thus delivered high and balanced carrier mobility. Pairing with Y6 as an acceptor, the PCE of OSCs exceeds 13%. These findings demonstrate that alkyl chain engineering can finely control the molecular orientation of OSCs towards high-performance OSCs.

Previous works have shown that regulating film-forming kinetics is decisive for the morphology of the active layer. From Jiangang Liu [6], the authors summarize the recent investigations concerning the employment of film-forming kinetics to optimize the morphology of the active layer, including the degree of crystallinity, the molecular orientation of the donor and acceptor, the domain size, and the lateral and vertical phase separation. Additionally, a future development trend of tuning the morphology of the active layer is briefly outlined, which may provide some guidance for further boosting the device performance of OSCs.

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